USDA UVB Monitoring and Research Network Langley Calibrations at Mauna Loa Observatory

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INTRODUCTION

The U.S. Department of Agriculture (USDA) ultraviolet B (UVB) Monitoring and Research Network [*Bigelow et al.,* 1998] set up a climatological site as well as an experimental research site at Mauna Loa Observatory, Hawaii (MLO), in November 1997 in order to investigate its new instrumentation's performance and ability to self-calibrate using the Sun as a source. The USDA Network makes measurements at 28 U.S. and 2 Canadian sites with the Yankee Environmental Systems (Turners Falls, MA) UV multi-filter rotating shadowband radiometer (UV-MFRSR). The measurements are made every 20 seconds and combined to 3-min averages. The UV-MFRSR [*Bigelow et al.*, 1998] is a seven-channel ultraviolet version of the visible multi-filter rotating shadowband radiometer described by *Harrison et al.* [1994]. This UV instrument contains separate solid-state detectors, each with nominal 2-nm full-width half-maximum (FWHM) ion-assisted-deposition interference filters at 300-, 305-, 311-, 318-, 325-, 332-, and 368-nm nominal-center wavelengths. The 368-nm wavelength is a standard WMO wavelength, and the others, except 300 nm, are close to Dobson wavelengths. The 300-nm channel was chosen as the shortest wavelength where sufficient signal-to-noise ratio was achievable. Each detector shares a common diffuser, thereby allowing total horizontal (no blocking) and diffuse horizontal (direct beam blocked by the shadowband) irradiance to be measured simultaneously at each passband. Direct normal irradiance is derived in near-real time by firmware included within the data-logging component of the instrument.

LANGLEY CALIBRATIONS

The Langley method of calibrating the UV-MFRSR was explored by *Slusser et al.* [2000] under the exceptionally clear skies at MLO. The objective of the study was to compare Langley calibration factors with those from standard lamps. This method has several advantages over the traditional standard lamp calibrations: the Sun is a free, universally available, and very constant source, and nearly continual automated field calibrations can be made. Although 20 or so Langley events are required for an accurate calibration, the radiometer remains in the field during calibration. Difficulties arise as a result of changing ozone optical depth during the Langley event and the breakdown of the Beer-Lambert law over the finite filter bandpass, since optical depth changes rapidly with wavelength. The Langley calibration of the radiometers depends critically upon the spectral characterization of each channel and on the wavelength and absolute calibration of the extraterrestrial spectrum used. Results of Langley calibrations for two UV-MFRSRs at Mauna Loa were compared with calibrations using two National Institute of Standards and Technology (NIST) traceable lamps. The two radiometers were run simultaneously: one on a Sun-tracker using a collimating tube and the other in the conventional shadowband configuration. Both radiometers were calibrated with two secondary 1000-W lamps, and later the spectral response functions of the channels were measured.

The range of air mass factors at a given wavelength suitable for Langley plots is governed by the sum of the products of the optical depths and the individual air mass factors. Extinction of the direct beam is much larger in the UV than in the visible region of the spectrum. This is the result of both the strong absorption due to ozone and the molecular Rayleigh scattering, which increases approximately as λ^{-4}, resulting in a combined optical depth exceeding 3.0 at 300 nm. Current state-of-the-art solid-state detectors are limited to not more than four decades of dynamic range. Therefore the range of air masses appropriate for UV Langley plots is more restricted than for the visible, where at 415 nm the total optical depth is typically less than 0.5. After a number of ranges were tried, an air mass range of 1.2 to 2.2 [solar zenith angle (SZA) 33.6° to 63.0°] was determined to be suitable for the UV, instead of the range of 2 to 6 (SZA 60.0° to 80.4°) commonly used in the visible part of the spectrum [*Harrison and Michalsky*, 1994].

Extrapolations to zero air mass voltage in the UV, central to the Langley calibrations, are more variable than those in the visible region as a consequence of the diurnal variations in the ozone and to a smaller extent aerosol optical depth. Large changes in ozone optical depth in the Hartley-Huggins band below 320 nm over the finite 2.0-nm passband of the UV-MFRSR result in the failure of the Beer-Lambert law, adding to the uncertainty of the Langley-derived calibrations [*Wilson and Forgan*, 1995]. Since the shorter wavelengths are attenuated more strongly than the longer as the SZA or column ozone increases, the effective center wavelength of the passband shifts to the red. Further complications result from the larger fraction of diffuse light in the field of view around the Sun's disc due to molecular scattering at these shorter UV wavelengths [*Tüg and Bauman*, 1994; *McKenzie and Johnston*, 1995]. Corrections for these problems were performed as discussed in *Slusser et al.* [2000].

The ratio of Langley to lamp calibration factors for the two radiometers after 213 days in 1998 for the seven channels from 300 nm to 368 nm, using the shadowband configuration, ranged from 0.988 to 1.070. The estimated uncertainty in accuracy of the Langley calibrations ranged

from ±3.8% at 300 nm to ±2.1% at 368 nm. For all channels calibrated with Central UV Calibration Facility (CUCF) lamps the estimated uncertainty was ±2.5%. The Langley and lamp calibration factors from two lamps agreed to within their combined uncertainties for all channels of the first radiometer and for all but one channel of the second radiometer. These are the first successful Langley cali-brations of filter radiometers at 300 nm and 305 nm. The Langley calibration factors with the radiometer in the shadowband mode for all the channels agreed with those derived from lamps, from 0% difference to at worst 7% higher at 300 nm. The uncertainty due to the radiometer signal-to-noise ratio is smaller using the Langley method than during lamp calibrations, which constitutes a major advantage of UV Langley calibrations for these radiometers.

There were no significant differences in Langley calibration factors when the radiometer was in the shadow-band configuration compared with when it was on the Sun-tracker. This suggests that in the UV the shadowband is equally as capable as the Sun-tracker in isolating the direct beam. This study shows that using Langley-method shadow-band UV radiometers at a high-altitude site is an effective method to obtain calibrations that approach the accuracy of those from lamps. Advantages over lamp calibrations include superior signal-to-noise ratio, automated operation, no loss of instrument operation, and reference to an absolute, nearly unchanging standard that is universally available. Used together with lamp calibrations, the Langley method provides continual checks of radiometer and lamp stability. The advantage of a shadow-band over a Sun-tracker radio-meter is that in addition to the direct beam the shadowband radiometer retrieves global and diffuse irradiances.

REFERENCES

Bigelow, D.S., J.R. Slusser, A.F. Beaubien, and J.H. Gibson, The USDA Ultraviolet Radiation Monitoring Program, *Bull. Am. Meteorol. Soc., 79,* 601-615, 1998.

Harrison, L., and J. Michalsky, Objective algorithms for the retrieval of optical depths from ground-based measurements, *Appl. Opt., 33,* 5126-5132, 1994.

Harrison, L., J. Michalsky, and J. Berndt, Automated multi-filter rotating shadowband radiometer: An instrument for optical depth and radiation measurements, *Appl. Opt., 33,* 5118-5125, 1994.

McKenzie, R.L., and P.V. Johnston, Comment on "Problems of UV-B radiation measurements in biological research: Critical remarks on current techniques and suggestions for improvements" by H. Tüg and M.E.M. Baumann, *Geophys. Res. Lett., 22,* 1157-1158, 1995.

Slusser, J.R., J.H. Gibson, D. Kolinski, P. Disterhoft, K. Lantz, and A.F. Beaubien, Langley method of calibrating UV filter radiometers, *J. Geophys. Res., 105,* 4841-4849, 2000.

Tüg, H., and M. Baumann, Problems of UV-B radiation measurements in biological research: Critical remarks on currents techniques and suggestions for improvements, *Geophys. Res. Lett., 21,* 689-692, 1994.

Wilson, S.R., and B.W. Forgan, In situ calibration technique for UV spectral radiometers, *Appl. Opt., 34,* 5475-5484, 1995.